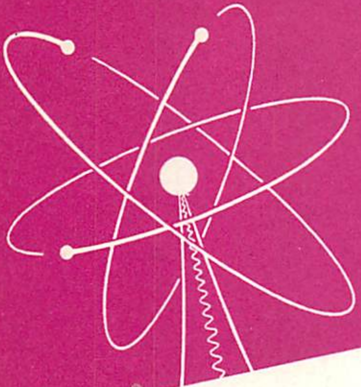
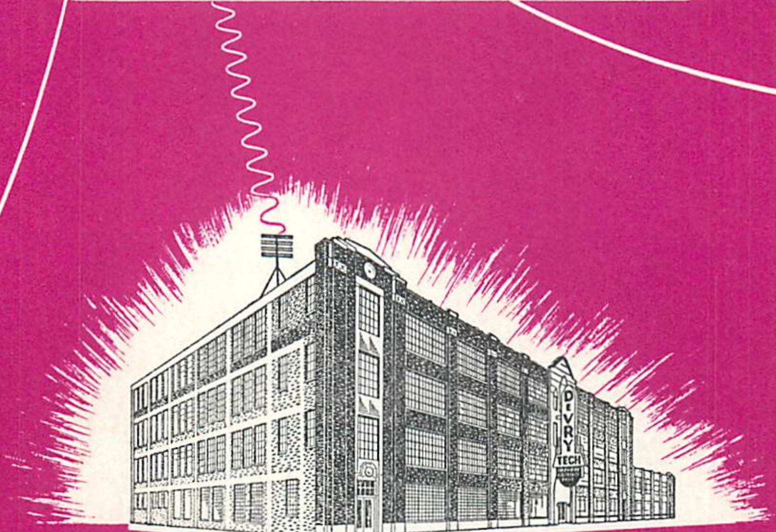


COLOR DEMODULATION

Lesson T4E-9A

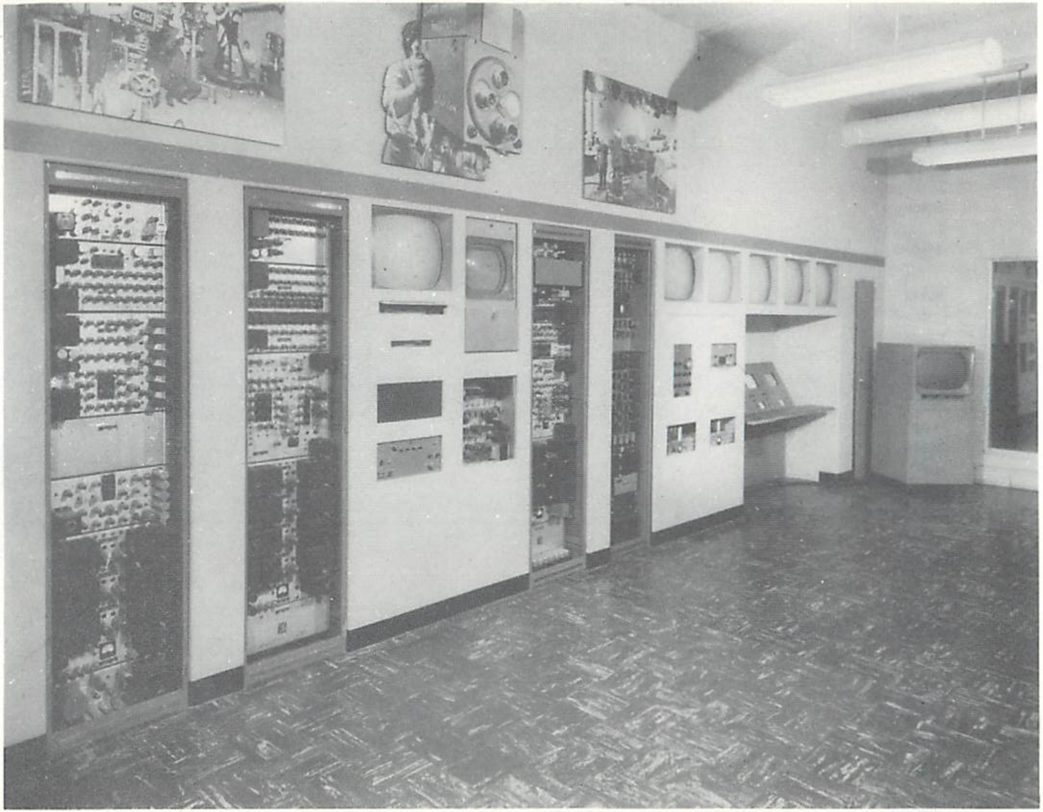


DeVRY Technical Institute
4141 W. Belmont Ave., Chicago 41, Illinois
Formerly DeFOREST'S TRAINING, INC.

T4E-9A

COLOR DEMODULATION

COPYRIGHT 1955
DE VRY TECHNICAL INSTITUTE, INC.



A corner view of the television laboratory studio in De Vry Tech's Chicago residential school. The color TV racks are in the foreground.

COLOR DEMODULATION

Contents

PAGE

The Color TV Transmitter 4

  Matrix 4

  Bandwidth 6

  Balanced Modulators 8

  Bandpass Filters 12

  Delay Networks 13

The Color Receiver 15

  Picture I-F 17

  Sound Channel 19

  Luminance Channel 20

  Chrominance Channel 20

  Synchronous Demodulation 21

Cross Talk 25

Delay Lines 26

The Matrix 28

Color Synchronization 28

Though Electronics is already a nearly indispensable factor in our daily lives, it is as yet only an infant science whose mature power can only be guessed at in the light of what has already been achieved.

Joseph Leeming
Peaks of Invention

COLOR DEMODULATION

In a previous lesson, we described the three basic attributes of color. These were brightness, hue, and saturation. Since only brightness is provided in a monochrome picture, two added characteristics must be included in the color television system.

However, to be compatible, reproduce a picture of pleasing quality, and still retain the 6 mc channel established for monochrome transmission, the signals have to be combined carefully to provide compact transmission with minimum interference.

THE COLOR TV TRANSMITTER

This signal multiplexing for color transmission requires circuits that are not used in the conventional black and white equipment. Possibly the outstanding new signal circuit in the transmitter is the balanced modulator. Before considering these circuits, however, again let's briefly trace the signal path from the camera to these modulators as shown in Figure 1.

When light is reflected from a scene into the camera, three output voltages, E_R, E_G, and E_B are produced. Each is directly proportional to the amount of its primary light reflected from the scene for that picture element.

These three voltages are immediately fed into an amplifier circuit called the GAMMA CORRECTION CIRCUITS. These amplifiers are designed to have non-linear characteristics which correct the primary color voltages so that the light output of the receiver picture tube is directly proportional to the light input to the camera. Once gamma corrected, these voltages are labeled E_R', E_G', and E_B'.

However, even gamma corrected color voltages are not satisfactory for the color transmission. For one thing, not one of the three represents the brightness of the scene. Therefore, individually they are not satisfactory for monochrome reception. Also, these three signals together supply far more information than is useful even in a color receiver.

Matrix

Therefore, all three voltages are fed into a matrix where samples of each voltage are combined to form three completely different output voltages labeled E_Y', E_Q', and E_I'.

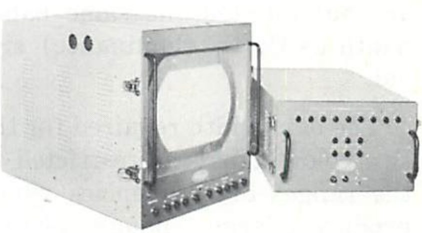
The samples of each color taken for the luminance signal are determined by how sensitive the eye is to the brightness in each color. As shown by the FCC equation for E_Y', the eye is about twice as sensitive to the green as the red, and only about 1/3 as sensitive to the blue as the red. Consequently the E_Y' voltage makes an excellent black and white picture for monochrome television and a complete brightness signal for color television.

The E_Q' and E_I' voltages on the other hand, do not determine the brightness. The amplitudes of these two signals determine the saturation of the color transmitted at the brightness of E_Y', the polarity of the signals and the ratio between their amplitudes determines the hue.

It is not necessary for E_Q' and E_I' to have equal bandwidths. The eye sees three colors for large areas but for somewhat smaller areas the green, yellow, deep blues, magenta, and purples all appear to the eye as some saturation of an orange-red or a greenish-blue. Therefore, at those frequencies which produce areas this small, one signal can be filtered out if the remaining signal by itself indicates one of these two colors when positive and the remaining color when negative.

This is precisely what is done in the matrix: positive E_I' represents various saturations of orange-red and negative values are in the green-blues. Therefore, E_Q' is not needed above .5 mc for good picture reproduction.

Where these signals would appear on the chromaticity diagram is shown in Figure 2. Remember that on the chromaticity diagram all the colors are of the same luminance. Notice how the "I axis" runs from the orange-red, through white, to the green-blue while the "Q axis" goes from green, through white, to the purples and "deep" blues. As a result of these two signals, E_I' and E_Q', a chroma signal can be developed which would project to any desired point on the diagram. Suggestive of these functions is the vector marked saturation. The amplitude determines how far out it reaches on the chromaticity diagram from white at point C. Hence, amplitude determines the saturation. The rotation of this vector around white places it over different hues on the graph.



The color TV monitor shown above is used to check the quality of color television signals.
Courtesy Polarad Electronics Corporation

The R, B, and G dots on this chart are the three primary colors as defined by the FCC for color telecasting. Therefore all hues and saturations within the triangle formed by lines joining these three dots can be reproduced by the system. Fortunately this covers a vast majority of the colors that appear in commonplace scenes.

Bandwidth

Because of the inability of the human eye to distinguish hue or saturation differences in small areas, the I and Q color signals are not allotted the same bandwidth as the Y (luminance) signal.

The bandwidth required for the two color signals is restricted to the ranges of frequencies which produces large enough picture areas for the eye to distinguish color differences.

Colors extending from purple to yellow-green constitute the color spectrum over which the eye has the least resolving power. Through experimentation, it has been found that a bandwidth of .5 or .6 mc is sufficient to handle this frequency spectrum. The Q chrominance signal is chosen to correspond to this band of colors.

Going back to the block diagram of Figure 1, a 0 − .5 mc filter in the E_Q' circuits limits this signal to the low frequencies at which a three color system is beneficial. From .5 to 1.3 mc two colors add to the picture quality, but above this frequency the picture areas are so small that no color is detected by the eye. Consequently, a 0 − 1.3 mc filter in the E_I' circuits cuts off all frequencies above this point. For these minute details, only the monochrome E_Y', signal is needed.

When a filter is included, it creates signal delay and the narrower the bandwidth the longer the delay. Consequently, delay lines must be included in the E_I' and E_Y' channels so that all three signals arrive at the transmitter modulator at the same instant.

As specified by the FCC, the E_I' voltage must be in quadrature with the E_Q' information and thus the two voltages are 90° apart in phase. Furthermore, the same FCC definitions specify that E_Q' is 33° from the phase reference. This forces E_I' to be $90° + 33°$ or 123° from the phase reference.

All these statements are shown pictorially in Figure 3A. For the sake of illustration E_I' and E_Q' are vector lengths representing some specific voltages at some luminance E_Y'. By completing the rectangle for E_I' and E_Q' in dotted lines, a line drawn from zero (0) to the opposite corner is the chrominance voltage E_C'. Thus E_C' represents all the hue and saturation in the televised scene. Note that the color difference or color minus brightness voltage $E_R' - E_Y'$ and $E_B' - E_Y'$ also produce the same vector length E_C'.

Considerable care was taken in the development of the color signal standards to make this possible. By means of these relationships a narrow band receiver can be built economically which demodulates the E_C' signal directly into two color difference signals.

For the given luminance of the televised scene, the vector E_C' represents the chrominance voltage of some specific saturation and hue on the chromaticity chart in Figure 2. Taking the phase reference as zero degrees in Figure 3A, the curved line representing zero degrees in Figure 2 is the same hue. The curve passes through white at point C and through point B. Thus, the colors along the curved line at 0° represent various saturations of blue.

At the 33° curved line in Figure 2 is the color representing various E_Q' voltages of Figure 3A. As the curve in Figure 2 passes through zero towards yellow, it becomes the 213° line. These yellows are the complementary colors to the blues. In Figure 3A, the vector $-E_Q'$ is at 213°, representing in vector form the complementary hue. Knowing how to compute the saturation and knowing the exact hue angle, locates one color on the chromaticity chart for a given luminance. However, insofar as color TV servicing is concerned, neither of these need be computed; only how each affects the overall signal should be understood.

The I and Q signals contain the color information in the televised scene, but these must modulate a given subcarrier in order to produce frequency interlace. Direct application of both signals to a single carrier would cause a complete mixture impossible to separate at the receiver.

Artificial delay lines are used wherever mounting space is an important factor.
Courtesy Shallcross Mfg. Co.

To overcome this difficulty, the color subcarrier, supplied to the I and Q balanced modulators, is two sine waves of the same frequency but 90° apart. This is indicated by the vectors of Figure 3A. With this arrangement, the color information of one signal can amplitude modulate one phase of the color subcarrier without any reaction with the other color signal which amplitude modulates the second phase of the color subcarrier. Therefore, simultaneous transmission of the two sets of color information without interaction between them is possible.

Information transmitted in this form can be detected and separated at the color receiver by heterodyning the modulated signal with a sine wave of the same frequency and phase as the carrier component used to generate this information. This process is referred to as SYNCHRONOUS DEMODULATION. It is the type of color detection found in broadcast television receivers.

Balanced Modulators

To suppress the color subcarrier, a balanced modulator circuit is used. This circuit arrangement produces sidebands but suppresses the carrier and other undesired frequencies.

Shown in Figure 3B is an amplitude modulated wave. Modulation is from 0 to 100% with the center line of the modulating wave being at 50%. During the modulation of a carrier, two sideband frequencies are produced and are present in the combined signal of Figure 3B. In Figures 3C and 3D the lower and upper sideband frequencies are represented. With the frequency of the carrier f_C and the frequency of the sine wave modulation voltage f_M, the lower sideband is at a frequency of $f_C - f_M$, and the upper sideband is at $f_C + f_M$.

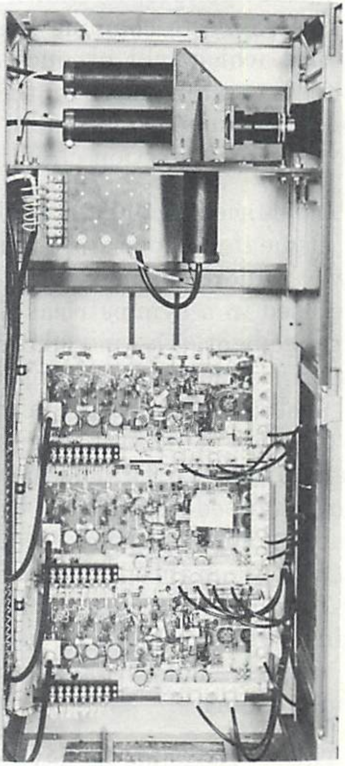
Furthermore, during the modulation process the phase angle between each sideband and the carrier is changing. This feature is best represented by using vectors as in Figure 3A. Therefore, using the peak amplitude of the carrier, and two sidebands as is indicated in Figures 3B, 3C and 3D as the proper vector lengths, we can show why the subcarrier of 3.58 mc must be suppressed. Notice that the unmodulated carrier amplitude is the 50% point.

We can represent all the conditions at points A, B, C, D, E, F in Figure 3B by vector diagrams in Figures 4A, 4B, 4C, 4D, 4E, and 4F. When the two sidebands produced are exactly in phase with the carrier as in Figure 4A, then the amplitude of the modulated wave is twice the amplitude of the carrier since the sidebands each have an amplitude of one-half the carrier. Thus, OM represents the amplitude at that time. In Figure 3B, this amplitude is at point A when the amplitude is twice the carrier. In Figure 4B, at another time the vector I_1 and I_2 are no longer in phase with the carrier, hence I_1 and I_2 must be added to vector C by vector addition to give M. In Figure 3B, this amplitude is at point B. In Figure 4C, when the two vectors cancel each other, the amplitude of the carrier at that instant is the amplitude modulated wave at point C in Figure 3B. When the vector I_1 and I_2 go in a downward or negative direction, the resultant in Figure 4D is OM still pointing in the same upward or positive direction as before.

This is point D in Figure 3B. When I_1 and I_2 are pointing in exactly the opposite direction in Figure 4E, the resultant is O, shown as point E in Figure 3B. When I_1 and I_2 swing past each other to complete one modulation cycle, the situation of Figure 4D is repeated, leaving a vector pointing positive. Point F in Figure 3B is this part of the cycle and the remaining cases are repeated to point G which is one complete modulating cycle later than point A.

Thus, no matter which part of the modulating cycle is chosen the resulting vector OM varies only between 0 and twice the amplitude of the carrier. Supposing I_1 and I_2 were the sidebands of the I signal. This would mean that two complementary colors as represented by Figures 4B and 4D would be at the same phase angle since their resultant OM is exactly in the same direction though of different amplitude. With the two complementary colors at the same luminance, they would necessarily have different saturations, even though they might have been at the same saturation originally.

In terms of Figure 3A, since the two carriers are not suppressed, all the hues must have angles between 0° and 90° since the amplitude of the resultant OM is never negative. This is definitely one limitation.



The light output from a color TV slide scanner is converted into electric signals through the use of the three multiplier phototubes shown mounted at the upper left.

Courtesy Allen B. Du Mont Laboratories, Inc.

On the other hand, when the subcarrier is suppressed, the modulation results are like Figure 5. Now starting with an amplitude equal to the subcarrier in Figure 5A, the resultant of the sidebands as indicated by vector OM reduces to zero at 5C and then swings negative reaching a full negative value at 5E. Finally it starts reducing toward zero again as shown at 5F. With the signal able to reverse polarity as shown here, it is possible to combine I and Q signals which will produce a resultant in any phase of the full 360°. This makes for more simple receiver detection circuits.

A balanced modulator is shown in elementary form in Figure 6. Two radio-frequency amplifiers are used in a symmetrical circuit arrangement. The modulating or signal frequency E_m is impressed in push-pull on the grids of the two tubes through the input transformer T_1 that has the usual center-tapped secondary. On the other hand, a carrier frequency E_C, is applied through transformer T_3 in such a manner that both grids contain the same polarity of carrier signal voltage at the same instant.

This is the same as having the two grids in parallel insofar as the carrier signal is concerned, but in push-pull as far as the modulating signal is concerned.

When the instantaneous polarity of the voltage present in the two halves of the input transformer T_1 secondary are considered, the net a-c voltages applied to the grids of the two tubes at a given instant are:

$$\text{For } V_1 \quad E_{G_1} = \frac{-E_m}{2}$$

$$\text{For } V_2 \quad E_{G_2} = \frac{E_m}{2}$$

As a result of the modulation process, the tube plate current contains three frequencies; the 2 sidebands $(E_C + E_m)$ and $(E_C - E_m)$, and the modulating signal (E_m).

The carrier frequency is eliminated during operation in this type of circuit. To illustrate this, assume a given carrier E_C is applied to transformer T_3 of Figure 6 (no modulation is present at this time).

Since the two grids are in parallel insofar as carrier voltage is concerned, both grids vary in the same direction. When one grid becomes positive, the other becomes positive also and, as a result, this causes the plate current of each tube to increase.

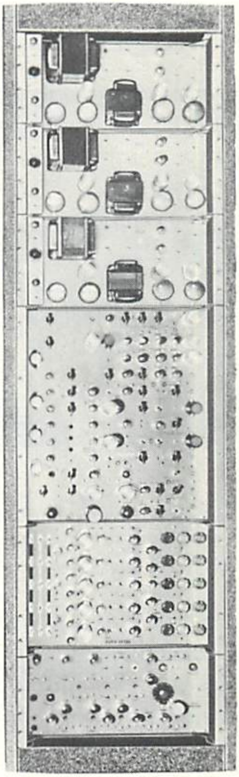
However, since the plate currents of these two tubes are equal and opposite through the primary winding of transformer T_2, the magnetic field created by one current is canceled by the magnetic field created by the other. The net result of the transformer flux is zero and hence, no carrier voltage appears across the secondary winding of transformer T_2.

Although the circuit of Figure 6 is basic, it illustrates the principles used in all balanced modulators. A commercial circuit is shown in Figure 7. Tube V_1 is a phase splitter which provides signal voltages equal in amplitude but 180° out of phase to the control grids of tubes V_2 and V_3. A d-c restorer supplies the d-c component of the video signal on each modulator grid.

This assures that all the signal information contains a definite relationship to the blanking level which is used as a reference for background brightness in the televised scene.

Tube balancing is essential in a balanced modulator in order to completely suppress the carrier. This is accomplished by control R_5 in the cathode circuit of V_2 and V_3. Adjustment of this control is necessary only when the circuit is placed into operation for the first time or when one of the modulator tubes is replaced. As described later, bandpass filters are included in the output circuits of these modulator circuits to remove other unwanted frequencies.

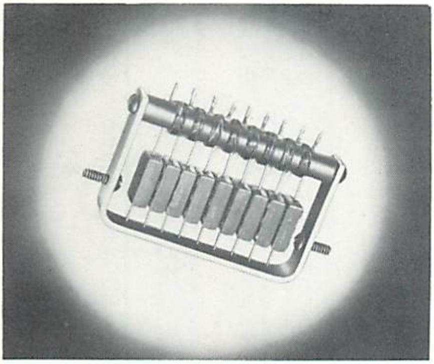
Although here the subcarrier is not connected in series with the modulating signals as shown in Figure 6, the end results are the same. One phase of the color subcarrier frequency is applied to the suppressor grids of V_2 and V_3.



The large chassis in the center of the above unit matrixes the simultaneous red, blue, and green video signals applied from a camera to produce a composite color picture signal which can be used to modulate a television transmitter.

Courtesy Wickes Engineering and Construction Company

At this point, it should be understood that a separate balanced modulator circuit, such as is shown in Figure 7, is used for each I and Q. Also, the color subcarrier signals are applied to each circuit 90° apart or in quadrature. As mentioned before, the additional 33° phase shift is included in the FCC specifications only to make an economical, narrow band receiver possible.



The length of signal delay is determined by the size of inductance and capacitance used in the construction of this delay line.
Courtesy Shallcross Mfg. Co.

With no modulating signal (E_I' or E_Q') present on the control grids of V_2 and V_3 each tube conducts proportional to the signal voltage present in its suppressor grid circuit. As indicated in Figure 7, the two grids are connected to voltages 180° out of phase, and each tube conducts on alternate half cycles. However, since the plates of V_2 and V_3 are tied together and to a common resistive load R_{12}, the plate current of V_2 increases each time its suppressor grid is driven positive by the exciting voltage.

In the meantime, the suppressor grid of V_3 is going negative and will cause its plate current to decrease by as much as the plate current of V_2 increases. With equal conduction of V_2 and V_3, no voltage (carrier component) exists across R_{12} and the carrier consequently is suppressed.

With a modulating signal applied, the information contained in the plate circuits of V_2 and V_3 will not be in balance. Since each tube conducts in accordance with the modulating signal present in its control grid circuit, a difference of r-f voltage is produced across R_{12}. V_2 and V_3 do not conduct an equal amount and this difference produces a voltage across R_{12}. This voltage is the sideband information.

Bandpass Filters

BANDPASS FILTERS are located following the output of the balanced modulators to limit the sideband information to a specific band of frequencies. Since only the sideband information is desirable, the original modulating signal which appears together with the sideband information, must be trapped out.

To illustrate this, consider the Q channel whose signal information is confined to a bandwidth of .5 mc.

With a color subcarrier of approximately 3.6 mc, the balanced modulators each produce two sidebands of information and the original modulating signal, while the color subcarrier is balanced out. Since the Q modulating signal is undesirable in the output, it must be eliminated.

Therefore, a bandpass filter is employed as shown in Figures 1 and 7 which passes only the sideband information. In this case, the frequencies passed in the Q channel vary from 3 to 4.2 mc and cause attenuation of the Q modulating signal since it falls below the lower frequency limit (3 mc). The frequencies, 3 and 4.2 mc, represent the sum and difference frequencies in the above illustration.

The information from the I balanced modulator has sidebands which extend 1.3 mc on both sides of the color subcarrier signal. However, as indicated in Figure 8, the upper sideband information of the I signal would extend beyond the allotted bandwidth of the transmitted signal and therefore, a portion of its upper sideband must be blocked. This attenuation takes place in the 2 to 4.2 mc bandpass filter following the I balanced modulator and the resultant I signal is transmitted as vestigial sideband information.

The outputs from the I and Q bandpass filters are combined to form the chrominance signal as represented by the vector arrangement in Figure 3A. The Q signal is shown shifted 33° from the phase reference axis whereas the I signal is in quadrature with the Q signal because of the phase displacement between the two color subcarriers.

As shown in Figure 1, this resultant chrominance signal is combined then with the output from the luminance channel to form the complete picture signal.

Delay Networks

Any deviation between the arrival time of the three signals affects the horizontal resolution and hue of the received image at the receiver. In passing through their respective bandpass filters, each signal experiences a time delay. This delay is proportional to the square root of the LC network comprising its filter. This relationship is shown in Equation (1).

$$T_d = \sqrt{LC} \qquad (1)$$

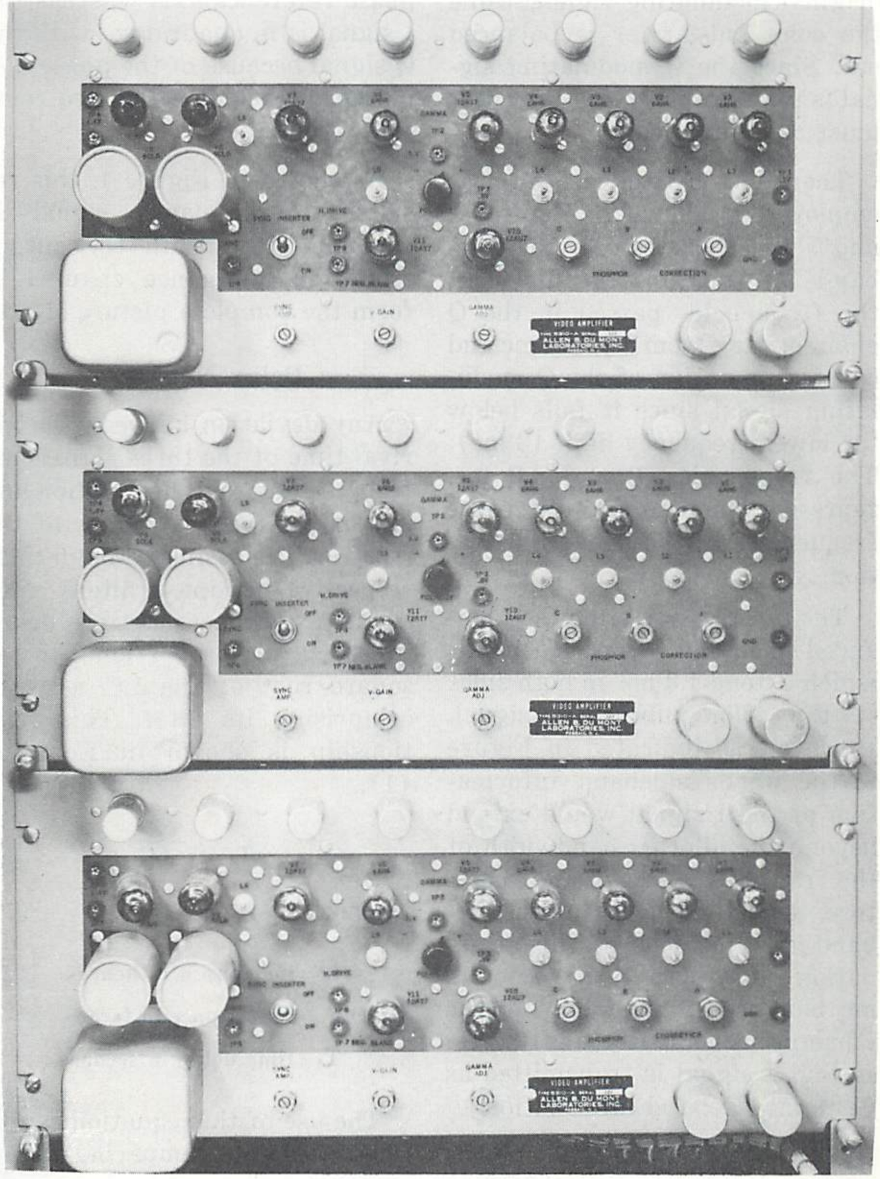
where:

L = inductance in henrys

C = capacitance in farads

T_d = time delay in seconds.

The use of this equation can be illustrated by comparing the I and Q signals prior to their application to the balanced modulators. For example, since the Q signal has its cutoff frequency limited



The bandwidths of these video amplifiers are approximately 8 mc.
One complete amplifier for each color.
Courtesy Allen B. Du Mont Laboratories, Inc.

to .5 mc, it is delayed an amount proportional to the LC network comprising its filter. In contrast, the low pass filter in the I channel has a cutoff frequency of 1.3 mc and as indicated by Equation (2) the (LC) term must reduce in order to allow a higher cutoff frequency.

$$f_c = \frac{1}{\pi\sqrt{LC}} \qquad (2)$$

where:

f_c = cutoff frequency of filter

π = constant.

That is, as the cutoff frequency f_c increases the value of LC must decrease as a result of their mathematical relationship. By substituting this lower LC term in Equation (1) it is seen that the time delay of the I channel is less in comparison to that of the Q signal. Therefore, in order that both signals be applied to the balanced modulators at the same instant, the I signal has a delay line inserted in series with its signal path.

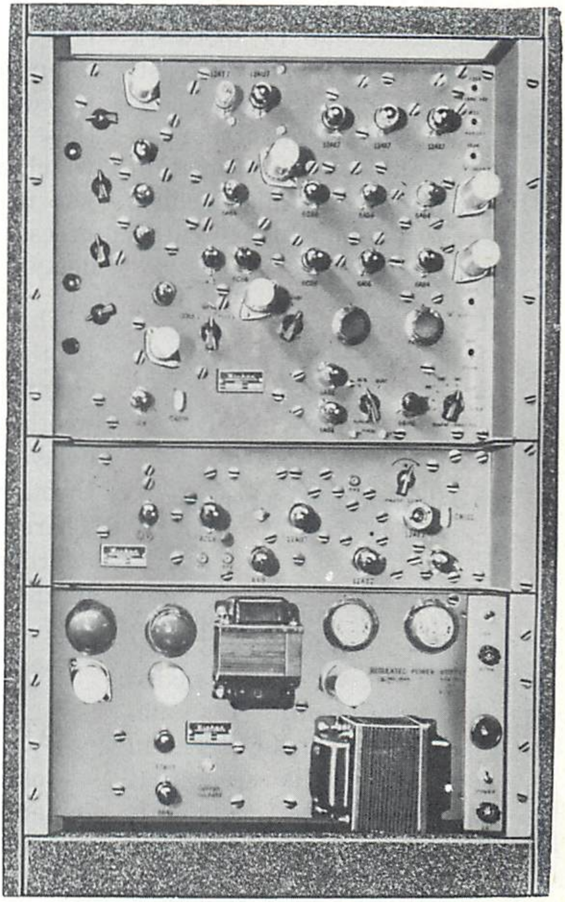
The amount of delay is determined by the time delay difference between the I and Q low pass filters. For example, assume the Q low pass filter has a delay of 3 microseconds while that of the I filter is 1.5 microseconds. The difference, (3−1.5 or 1.5 microseconds) between these two delays, determines the added delay required in the I channel in order to equalize the arrival time of these two signals. If a delay cable which has a .5 microsecond delay per foot is used, three feet are necessary to provide the required delay.

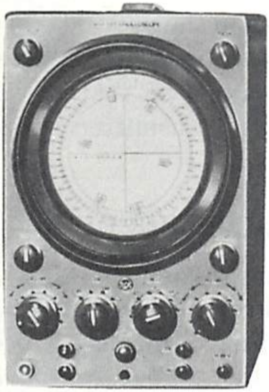
This same principle is repeated in the Y channel. Since the Q channel has the narrowest bandwidth, the signal through it is delayed more than the signals through the I and Y channels. Therefore, as in the previous case, a proper delay must be inserted in the Y channel so that it will arrive at the transmitter at the same time.

THE COLOR RECEIVER

Color transmission contains luminance, chrominance, blanking, and sync signal information necessary for the proper reproduction of a televised image on either a color or monochrome television receiver. Due to the NTSC compatibility requirements, this transmitted signal must produce a monochrome version of the color image on a black and white receiver of quality equal to or superior to normal monochrome reception without any modifications.

The transmitted color picture signal is similar to the one used in monochrome broadcasts in that





Used in studio work this unit displays the chrominance components of standard color bar signals in vector form on the scope screen shown at the lower left.

Courtesy Wickes Engineering and Construction Company

it contains the same frequency allocations; that is, channel width, location and spacing of the sound and picture carrier and their sidebands. Other similarities are that it contains the same scanning methods, the same synchronizing signals, and the same modulation polarity as used in monochrome reception.

As specified in an earlier lesson, the bandwidth of the chrominance and luminance signals determines three ranges of picture detail.

In the first range, fine picture details, corresponding to video frequencies above 1.3 mc, are reproduced in monochrome (black and white). The eye cannot distinguish colors in the picture details until the video frequencies are reduced down to 1 megacycle.

On the second range, areas corresponding to video frequencies, between .5 mc and 1.3 mc reproduce colors in a two-color system. The colors involved range from an orange-red to a green-blue. Reference to the color triangle of Figure 2 illustrates this range of colors.

In a third frequency range, still larger areas, corresponding to video frequencies below .5 mc, reproduce the full three color system.

Receivers capable of reproducing these three frequency ranges are considered as WIDE-BAND CHROMINANCE receivers. These receivers, have sidebands as shown in Figure 8. Notice that the Q signal has double sidebands while the I signal is like the luminance signal. That is, it contains the lower sideband and only a portion of the upper. So long as the band pass filters of a receiver do not cut off the video frequencies below .5 mc, the receiver will reproduce the described 3 color ranges without encountering any difficulty.

For simplicity, a receiver may have bandpass filters which reject any color video frequencies above .5 mc and thus the I and Q signals will each have double sidebands limited to .5 mc. In receivers of this type, color information for picture detail which exists in the frequency range between .5 mc to 1.3 mc is lost. Units of this type are known as NARROW-BAND CHROMINANCE receivers.

Picture I-F

The picture i-f bandwidth in color receivers is increased to about 4.2 mc in order to accommodate the newly added color information. Since this color information is produced by a subcarrier close to the sound carrier frequency, care must be exercised to prevent cross modulation between these two signals. Interference of this type takes the form of a 920 kc beat note that produces a cross hatch pattern on the viewing screen.

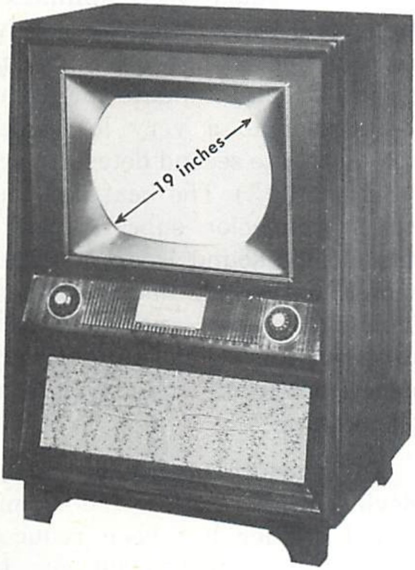
Cross modulation is minimized in several ways in a color receiver. (1) Special networks are employed which attenuate the sound i-f carrier to a very low level. (2) Separate second detectors are used; and (3) The beat note between the color subcarrier and the 4.5 mc sound is an odd harmonic of the half line frequency. Therefore, dots normally produced by this type of interference cancel out in alternate frames of the picture.

To assure this cancellation, the deviation tolerance of the 4.5 mc sound carrier has been reduced from the former 5,000 cps to 1,000 cps. Since the 4.5 mc sound signal is still dependent upon the difference frequency between the picture and sound carrier, this tighter restriction conforms to the compatibility requirements.

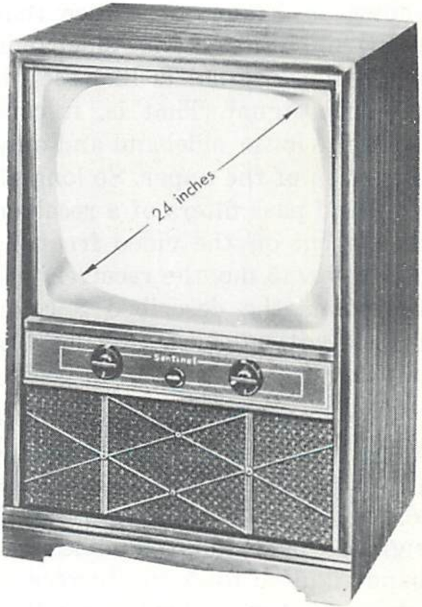
Typical networks used for sound attenuation are shown in Figures 9 and 10. In Figure 9, the output signal from the tuner is fed to a LINK COUPLED, BRIDGED-T NETWORK which in turn is tuned to reject the sound carrier. With the proper setting of R_2, attenuation of 30 db is readily obtained.

Frequencies other than the 41.25 mc sound carrier are coupled through C_3 to the grid of the first picture i-f amplifier. Coil L_4 is tuned to peak up the frequencies immediately following the attenuated sound carrier. This allows complete passage of the color sideband information.

A wide bandwidth is obtained through the use of a bandpass filter located in the plate circuit of this first picture i-f amplifier. Coil L_9 provides the desired bandwidth together with the aid of the series resonant rejection traps tuned to the adjacent picture i-f



COLOR TV—Picture Area 205 sq. in.
Power Consumption about 500 watts.
Courtesy Raytheon Mfg. Co.



BLACK and WHITE TV—Picture 355 sq. in.
Power Consumption 250 watts.
Courtesy Sentinel Radio Corporation

(39.75 mc) and sound i-f (47.25 mc) signals.

Another system used for early sound attenuation is shown in Figure 10. Here, the output from the tuner is applied directly to the grid of the first picture i-f amplifier through a series tuned 41.4 mc circuit. This circuit is used to peak up the video frequencies in this region because they contain the color sideband information.

Therefore, upon adjustment of the 41.25 mc absorption sound trap located in the plate circuit of the first i-f amplifier, the band of frequencies immediately following this lower sound carrier are not attenuated by any appreciable degree.

The remaining i-f stages in both color receivers are transformer-coupled, stagger-tuned stages in order to obtain the proper wave shape and response.

As in the case of monochrome receivers, the sound signal is kept to some minimum as compared to the picture carrier so as to produce a difference signal of 4.5 mc with a minimum of amplitude variations. By maintaining the sound i-f carrier at this low level, the resultant 4.5 mc signal has the original FM modulation of the transmitted sound and any small amplitude variations produced are readily suppressed by the FM detector.

Sound Channel

A separate detector is used to separate the sound from the transmitted picture signal information in order to further prevent a heterodyne between the sound and chrominance signals. In Figure 11 sound take off is shown to occur after the last picture i-f amplifier. In this manner, trap circuits may be employed following this take off point to further minimize the possibility of producing cross modulation between the sound and chrominance subcarrier.

One arrangement for sound detection is shown by the partial diagram in Figure 12. Here, the sound signal is coupled through C_1 and detected by a crystal diode S_1. The output is fed then to a tuned circuit (L_1C_2) which is resonant to the 4.5 mc difference frequency. Beyond this point, the 4.5 mc signal is amplified and converted to audio in the conventional manner. Even though separate sound detection is used in color receivers, the sound circuit still retains its intercarrier characteristics. That is, the effect of any frequency drift in the receiver local oscillator has little or no effect on the sound tuning. It is still dependent upon the difference in frequency between the transmitted sound and picture carriers.

A bridged-T, bandpass filter circuit is located between the plate circuit of this last picture i-f amplifier and the video detector. The bridged-T trap is tuned to reject the 41.25 mc sound carrier thus minimizing its reaction with the chrominance signal. The capacitance formed between L_5 and ground helps to maintain the broad bandpass provided by this type of filter.

Luminance Channel

After detection, the color picture signal is fed to a video amplifier where it is amplified and separated into proper channels. As shown in the wide band chrominance receiver of Figure 13A, the luminance signal is coupled through a 1 microsecond delay line and amplified by a second video amplifier.

The delay line serves to delay the luminance signal so that its arrival time at the matrix is matched with the I and Q color signals. A deviation greater than .05 microseconds between the arrival time of any of the three signals (I, Y, or Q) results in poor color reproduction; poor horizontal resolution, and incorrect hues and saturation of the televised image.

The second video amplifier builds up the luminance signal to an amplitude sufficient for application to the matrix and color picture tube. Frequently, the response of the last video amplifier in monochrome receivers extends beyond 4.5 mc in order to accommodate the sound difference frequency. However, in color receivers, attenuation of the 3.6 mc color subcarrier is desired in order to minimize the interference it exerts on the viewed image. Therefore, the response of the video amplifiers after the chrominance signal is removed usually is slightly less than 3.6 mc.

Since the luminance signal contains the same signal information as the present signal used in monochrome transmission, it requires no further consideration at this time.

Chrominance Channel

In Figure 13A the chrominance signal is obtained by passing the detected color picture signal through a bandpass amplifier and filter. The bandpass filter is designed to pass only those frequencies containing the color sideband information; namely, frequencies extending from 2 to 5 mc. A curve representative of this bandpass filter is shown in Figure 14A.

To illustrate the features of this bandpass filter, refer to the circuit of Figure 15. The choice of the L and C components used in the construction of the resonant circuits (L_1C_1) and (L_2C_2)

determine the frequency limits of the filter.

For instance, at frequencies below 2 mc, the bandpass filter takes on the characteristics of a high pass filter and passes only those frequencies above 2 mc as shown by the bandpass curve of Figure 14A. In a similar manner, this filter possesses low pass characteristics at the upper frequency limit (5 mc); that is, it passes all frequencies up to 5 mc while attenuating all others.

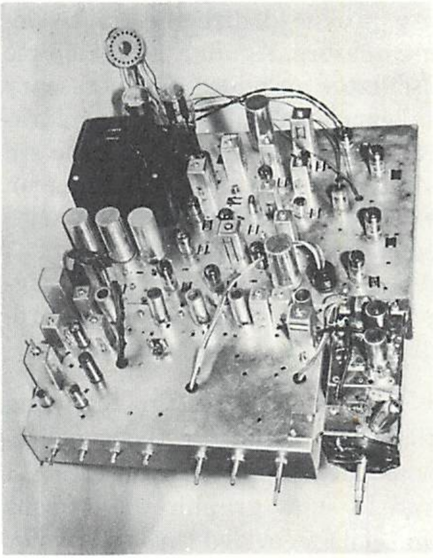
Used in this manner, the combination of the shunt and series arm passes only those frequencies contained in the chrominance signal.

As a low terminating impedance at the output of this filter, the 500 ohm chroma control R_1 has two main advantages. (1) It prevents self biasing of the I and Q demodulator stages and (2) It serves to minimize subcarrier feedback between the two demodulators.

Synchronous Demodulation

Color data, carrier by the chrominance signal, contains the hue and saturation of the televised scene. As mentioned earlier, these signals were transmitted in quadrature in order to simplify separation and detection at the receiver.

To recover the two sets of color information independently, synchronous demodulation is necessary. In this process, the modulated information is heterodyned with a locally generated sine wave having the same frequency and phase as the carrier from which the desired modulation was generated.



A top view of the signal circuits in a color television receiver.

Courtesy Sentinel Radio Corporation

As shown in Figure 13A, a cw signal, generated at the color subcarrier frequency, is applied to the I and Q demodulators at a given phase. The quadrature amplifier provides the 90° phase between the two 3.579545 mc signals the same manner in which the

I and Q subcarrier signals were shifted at the transmitter.

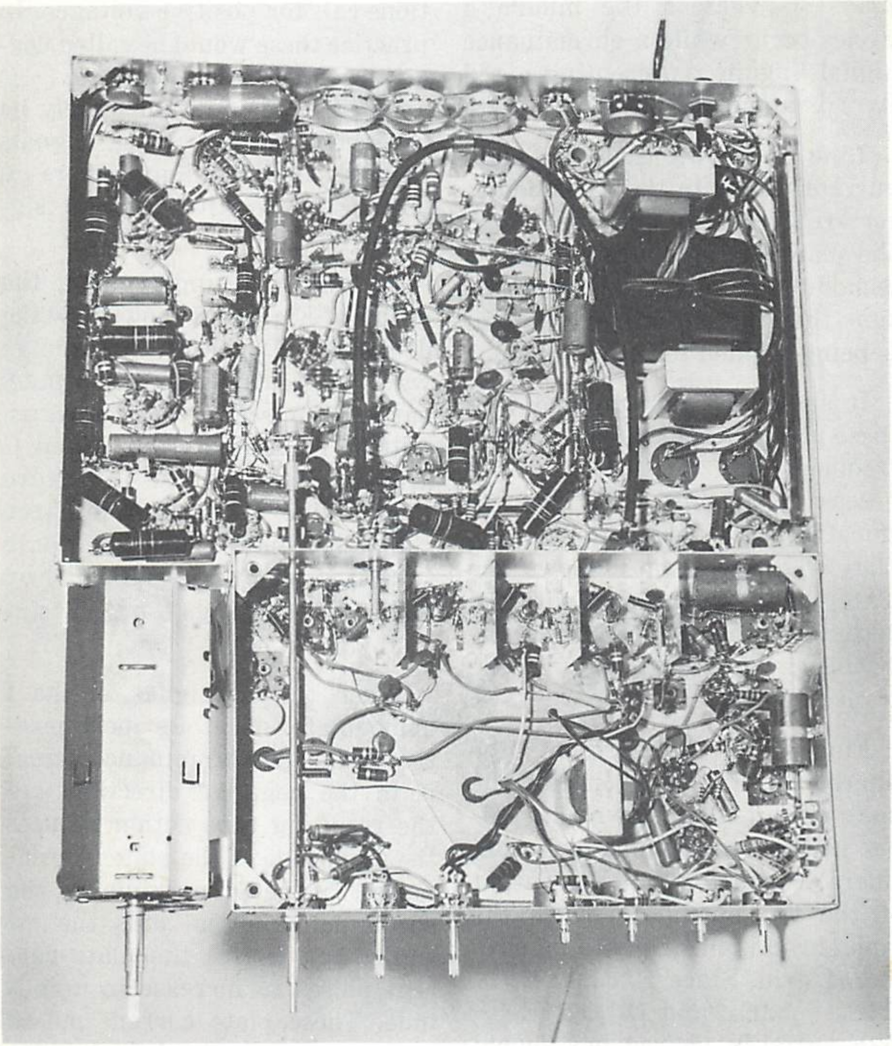
For the narrow band chrominance demodulator, Figure 13B shows those circuits that differ from those of Figure 13A. Notice that the R′-Y′ and B′-Y′ signals are produced directly at the demodulators. Again a local 3.58 mc oscillator provides the necessary subcarrier frequency. A quadrature network phase shifts the sin ωt to a cos ωt, thus providing an exact 90° displacement of two subcarriers. Since there is no 33° phase shift, R′-Y′ and B′-Y′ signals instead of I and Q are produced by the demodulators.

For convenience in following the basic action of the synchronous demodulators, Figures 17 and 18 show graphic wave-forms and pulses carried through two or more cycles of the cw oscillator.

At the left in Figure 17, the graph shows the voltage and current wave-forms in the I demodulator, while the right side of the graph shows the Q demodulator action. The wave-form on line A is the cw signal that is applied to the suppressor grid (#3). Notice that the "Q" demodulator cw signal lags the I demodulator cw signal by 90°. Both demodulators are biased so that they conduct only during the most positive portion of the cw signal. This causes narrow plate current (I_p) and plate voltage (E_p) pulses as shown in relation to reference lines B and C.

Next, line D shows the added chrominance signal that will be present on the control grids (#1) of both demodulators when a red "bar" signal is being scanned at the transmitter. This chrominance signal representing red lags the I cw signal by about 20° and leads the Q cw signal by about 70°. Tube action causes the voltage on grid #1 of the I demodulator to be positive and conduction results in plate current (I_p) pulses of line E to be greater in amplitude than those of line B.

This same chrominance signal also causes the grid #1 of the Q demodulator to become positive with a subsequent increase in the amplitude of the plate current pulse on line E. A careful examination of the wave-forms on line D shows that the chrominance signal on grid #1 of the Q demodulator is only slightly positive at the instant of time when the cw signal on grid #3 of the Q demodulator is at its maximum positive value. This means that the increase of plate current in the Q demodulator will be less than the increase of plate current in the I demodulator. In turn, the changes of plate voltage on the Q demodulator will be less than on the I demodulator. These corresponding



An under chassis view of the color TV receiver shown in the previous illustration. Note the delay line bent into a "U" shape.

Courtesy Sentinel Radio Corporation

changes of plate voltage waveforms are shown on line F.

In order to explain how these variations enable the I and Q signals to be recovered in the plate circuits of the demodulators, line G shows 8 cycles of the cw signal applied to grid #3 of each demodulator. The first two and the last two cycles are present with no chrominance signal applied to grid #1 whereas the middle 4 cycles occur while a chrominance signal (again representing a red bar) is applied to grid #1.

Line H shows that the plate current pulses in the I demodulator are greater in amplitude than the plate current pulses in the Q demodulator during the period of time that the chrominance signal is being applied to the #1 grids.

It should be remembered that these plate current pulses are at a frequency of 3.58 mc and it is necessary to insert a filter to smooth out these variations in the plate voltage. Line I shows the plate voltage wave-form with the dotted portions representing the discharge of the capacitor in the plate circuit.

Finally, line J represents the filtered voltage wave-forms in the plate circuits. As shown, the output of the I demodulator is considerably greater than the output of the Q demodulator with the same chrominance signal applied to the #1 grid. Since $E_I' = .60\ E_R' - .28E_G' - .32E_B'$ and $E_Q' = .21E_R' - .52E_G' + .31E_B'$, a red bar should cause the output of the I demodulator to be about 3 times the output of the Q demodulator and these conditions are illustrated in line J.

Notice here that the outputs of the two demodulators are negative voltages whereas the equations call for positive voltages. In practice these would be called negative polarity demodulators (−Q and −I) and it would merely be necessary to put these signals through individual amplifiers to obtain the positive polarity signals.

Following a similar plan, the graph of Figure 18 shows how the demodulator current and voltage wave-forms change when a BLUE bar is being scanned at the transmitter. Wave-forms A, B, and C are identical to those in Figure 17. On line D, the chrominance signal has now shifted in phase so that it lags the I cw signal by about 135° and lags the Q cw signal by about 45°.

When the cw signal on the I demodulator is at its most positive peak, the chrominance signal is in the negative direction and the resulting tube action reduces the amplitude of the plate current pulses. In the Q demodulator, the chrominance signal aids the cw signal and causes the plate current pulses to increase in amplitude. These plate current pulses and the resultant plate voltage pulses are shown on lines E and F.

Once again, line G shows several cycles of each signal with the resultant changes in plate current and plate voltage on lines H and I. Line J shows that the output of the I demodulator is approximately equal to the output

Figure 16 Q Demodulator

of the Q demodulator but the two signals are opposite in polarity.

Referring again to the equations:

$$E_I' = .60E_R' - .28E_G' - .32E_B'$$

$$E_Q' = .21E_R' - .52E_G' + .31E_B'$$

we see that the output of the I demodulator should be −.32 and the output of Q demodulator should be +.31 when a blue bar is being reproduced. Since line J shows the I output as positive and the Q output as negative signals, these demodulators would be considered negative polarity demodulators, and amplifiers can be used to obtain the positive polarity signals.

Several other types of circuits can be used for the synchronous demodulators and these will be taken up, when encountered, in a later lesson. However, regardless of the circuit employed, the basic action remains the same.

Cross Talk

Up to this point, we have described the manner in which the desirable signals are obtained from the synchronous demodulators. Unfortunately, unless the proper precautions are taken, it is very possible for one signal to find its way into the other circuits. This interaction between the I and Q signals is called **"crosstalk"**.

Since the Q signal is transmitted with both sidebands containing information from zero to about .5 mc the I signal also has two sidebands containing low frequency information but only one sideband for information from .5 to 1.3 mcs.

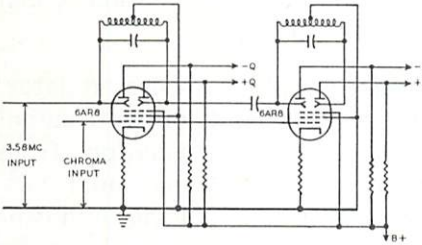
In the I demodulator, the two sidebands of the Q signal produce voltages that are equal in amplitude but opposite in polarity so that the Q voltage in the output of the I demodulator is zero. This is a characteristic of the synchronous detector which enables the use of this circuit to recover the information which is in phase with the re-inserted subcarrier and eliminate information which is not in phase.

Likewise, in the Q demodulator, the two sidebands of the I signal that contain information from zero to .5 mc produce equal voltages of opposite polarity and cancel each other. That portion of the I signal containing information from .5 to 1.3 mcs has only one sideband and this information would appear in the output of the Q demodulator as crosstalk if additional steps were not taken to eliminate it.

To prevent this crosstalk, the output of the Q demodulator is fed to a low pass filter as shown in Figure 16 which has a frequency response from zero to .5

mc. This filter eliminates the high frequency I signals from the Q channel.

In narrow-band receivers, the R-Y and B-Y demodulators function in the same basic manner as the I and Q demodulators of a wide-band receiver. One of the differences between the two systems is that the cw signal applied to the narrow band demodulators is not shifted 33° as it is in the wide band system. It is also necessary to restrict the frequency response of the R-Y and B-Y output circuits to .5 mc in order to prevent crosstalk.



Schematic diagram of two 6AR8 tubes being used as synchronous detectors in a color television receiver.

The main difference between the narrow-band and wide-band receivers lies in the circuits following the demodulators. Since the R-Y and B-Y signals are obtained directly from the outputs of the narrow band detectors, it is merely necessary to add the Y signal to recover the original Red and Blue voltages. The G-Y voltage can be obtained by mixing the proper amount of R-Y and B-Y signals. To this is added the Y signal in order to obtain the original Green voltage.

It will be found in some narrow band receivers that the Y signal is applied to all three cathodes of the color picture tube and color-difference signals to the grids. With the R-Y signal on the grid and the proper polarity Y signal on the cathode, the total voltage applied between cathode and grid is R-Y + Y which is equal to R and is the desired voltage. Similar relationships hold true for the signals applied to the other two guns.

The disadvantage of narrow-band receivers is that three color reproduction goes to .5 mc and black and white from .5 to 4 mc. No two color system exists between .5 and 1.3 mc. However, it does provide an economical alternative where the slight impairment of the picture quality is very acceptable.

Delay Lines

Since the bandwidth of the I channel is greater than the Q, a delay in the I channel is necessary so as to equalize the arrival time of these two color signals at the matrix in a wideband chrominance receiver. The Y signal must also be delayed to make it coincide with the I and Q signals.

Regular transmission lines may be inserted in series with the signal to be delayed. However, when long time delays are necessary, the length of transmission line becomes excessive and presents a space and mounting problem. Therefore, to accomplish the same delay in a minimum space, artificial lines are used. These lines contain lumped elements of inductance, capacitance, and resistance and have characteristics similar to actual transmission lines.

A typical delay line used in color receivers is shown in Figure 19. The portions indicated by A, B, and C are called sections and each section delays the signal by an amount equal to $\sqrt{L_1C_1}$; where

L_1 = the inductance in henrys

C_1 = the capacitance in farads

For a delay using "n" number of sections, the time delay encountered by the line is,

$$\textbf{Time delay } (t_d) = n\sqrt{L_1C_1}$$

When an artificial line is terminated in its characteristic impedance "Z_0", it functions as a low pass filter and passes frequencies from zero to a cutoff frequency determined by the inductance and capacitance used in the line construction. Used in this manner, an artificial delay line serves a dual purpose. The line RETARDS AND BAND LIMITS THE APPLIED signal.

The length of delay required in the I channel is .5 microseconds while the luminance channel, which contains the widest bandwidth, requires about 1 microsecond of delay.

The output from the Q low pass filter is applied to a phase splitter from which a positive and negative output is obtained for application to the matrix network.

The output from the I low pass filter is applied to an amplifier which produces a signal equivalent in amplitude to the Q signal. Since both sidebands of the Q signal were transmitted, its amplitude is flat throughout the Q channel. However, the I signal was transmitted with one of its sidebands suppressed in order to conform to the FCC channel spacing requirements.

Therefore, this amplifier is used to compensate for the signal amplitude variations that result.

The output from this I amplifier is applied to a phase inverter whose purpose is to obtain two polarities of signal voltage. The output from the I amplifier provides the positive signal while the output of the phase inverter produces a negative signal.

The Matrix

The four output voltages, produced by the I and Q channels, are added in a resistive network called the matrix. One such circuit is shown in Figure 20A. Here they combine with the luminance (Y) signal and develop voltages in such proportions that they provide the proper input signal for each color amplifier. The values indicated at the input to the matrix reveal the ratios of the I, Q, and Y signals necessary for good color reproduction.

The chosen percentages of each of the three signals Y, I and Q are required to reproduce the same colors originally present in the transmitter matrix from the color TV camera. The table in Figure 20B lists the various values of each required signal, with the minus voltages indicating a phase reversal of 180° from the plus voltages.

The results of these mixed proportions are amplified to increase E_G', E_B', and E_R' to the proper level for application to the grids of the color picture tube. Since the red phosphor requires more drive than the blue and green phosphors, the red amplifier is operated at maximum gain. Both the blue and green amplifiers have gain controls which reduce their respective signals to equalize the light output for the three colors.

Color Synchronization

As indicated earlier, the color signal consists of two sets of information in quadrature and in order to demodulate this information, a sample signal, of the same phase and frequency as the color subcarrier generated at the transmitter, was required. Therefore, to accomplish this action a color burst signal, the frequency of which is equal to the color subcarrier at the transmitter, is transmitted along with the complete picture signal. This color burst is at least 8 cycles at 3.579545 mc located on the "back porch" of the horizontal blanking pulse as shown in Figure 21.

A trap circuit, tuned to this burst frequency, is located in the output of the first video amplifier. From here, it is applied to a burst amplifier which under normal conditions is held cut off during the video portion of the transmitted picture signal. To minimize spurious conduction of this amplifier, a horizontal pulse is used to trigger the burst amplifier so that it conducts only during the presence of a color burst signal. By using an afc circuit to control the receiver 3.579545 mc sample oscillator, the color burst signal serves as a reference when applied to the phase detector to which the receiver sample oscillator is compared.

As shown in Figure 22, any correction voltage developed as a result of a frequency difference between these two signals is applied to a reactance tube. A positive correction voltage results in a reduction of the receiver color oscillator frequency whereas a negative correction voltage naturally has the opposite effect. The sample oscillator is held well within 5° of the original color subcarrier frequency in order to maintain the proper hue of the televised image.

The color phasing amplifier, used in wideband receivers only, is located between the sample oscillator and phase detectors. This stage permits the carriers generated for the I and Q signals to be phase shifted 33° from the phase reference axis as specified by the FCC.

Once the 3.579545 mc cw signal has been generated, it is fed to a quadrature amplifier whose function is to shift the input signal by 90°. A circuit providing this action is shown in Figure 23. Here, the arrangement of the tuned transformer in the plate circuit of V_2 is such that the primary C_5L_3 acts inductive. Due to this condition, instead of obtaining a normal 180° phase inversion between the input and output signals applied to V_2, the inductive primary causes the tube current to lag by approximately 90°. Since the secondary voltage is dependent upon the primary current, this induced voltage also is shifted approximately 90°. This fulfills the requirements of producing two 3.579545 mc signals in quadrature for the I and Q demodulation stages.

One signal, $\sin(\omega t + 33°)$, is taken directly from the sample oscillator and applied to the Q demodulator. The quadrature signal, $\cos(\omega t + 33°)$, is the oscillator output phase shifted 90° and then applied to the I demodulator.

During transmission periods wherein no color signal is transmitted, a circuit called the "color killer" disables the chrominance channel. Its purpose is to prevent video information from passing through the bandpass amplifier and subsequent circuits.

Any signal through these circuits during monochrome transmission would result in improper shading of the detail information because of the possibility of spurious color mixtures combining with the black and white signal at the picture tube.

With a color burst signal present, as during color transmission, the phase detectors conduct and develop a negative voltage which is applied to the color killer tube. This voltage is sufficient to render the color killer inoperative and thus permits proper color reproduction.

During monochrome broadcasts, the absence of a color burst removes the negative bias from the color killer tube and thus permits it to conduct. This conduction causes a large negative voltage to be developed in the grid circuit of the bandpass amplifier and blocks the passage of the chrominance signal to the color demodulators.

Although mentioned only briefly in relation to color demodulators, color synchronization circuits are very important. Good color can only be obtained when the local oscillator is held in proper phase. However, to do this requires automatic phase control circuits. These circuits are described in the next lesson.

* * *

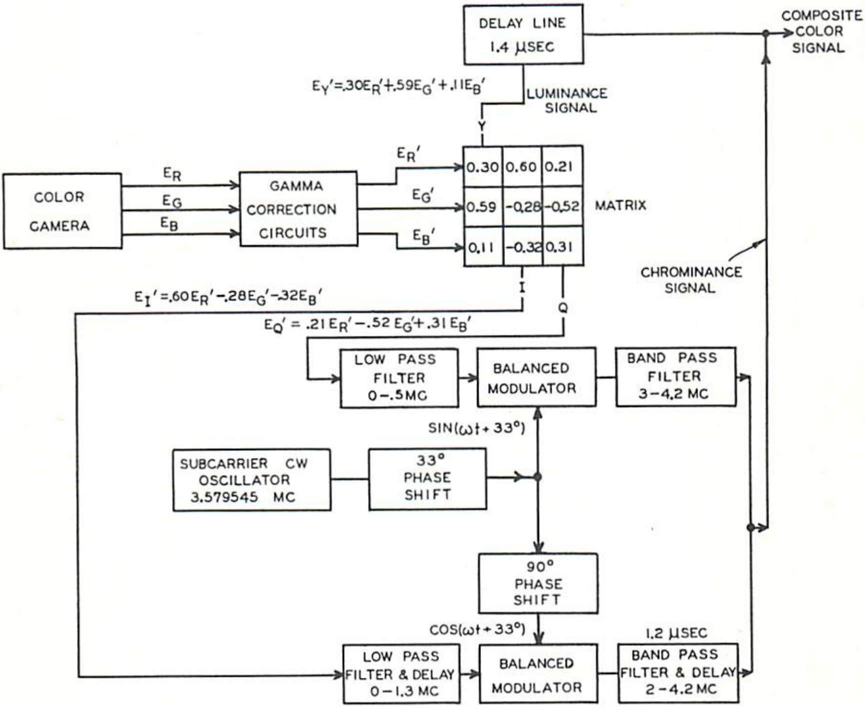


FIGURE 1

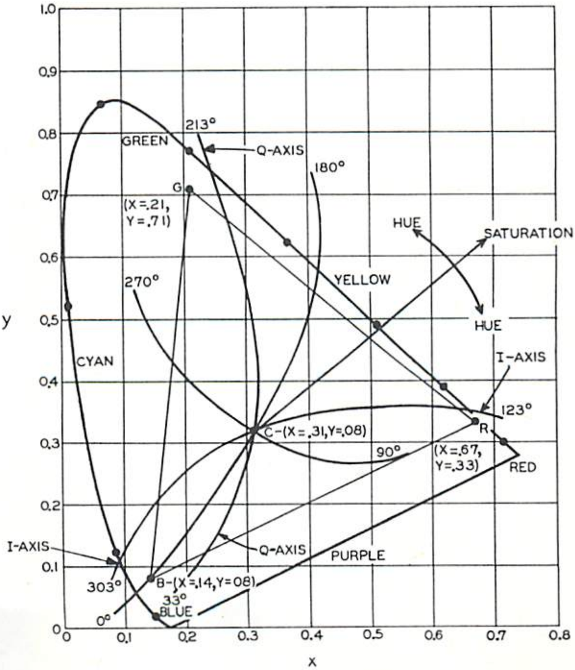


FIGURE 2

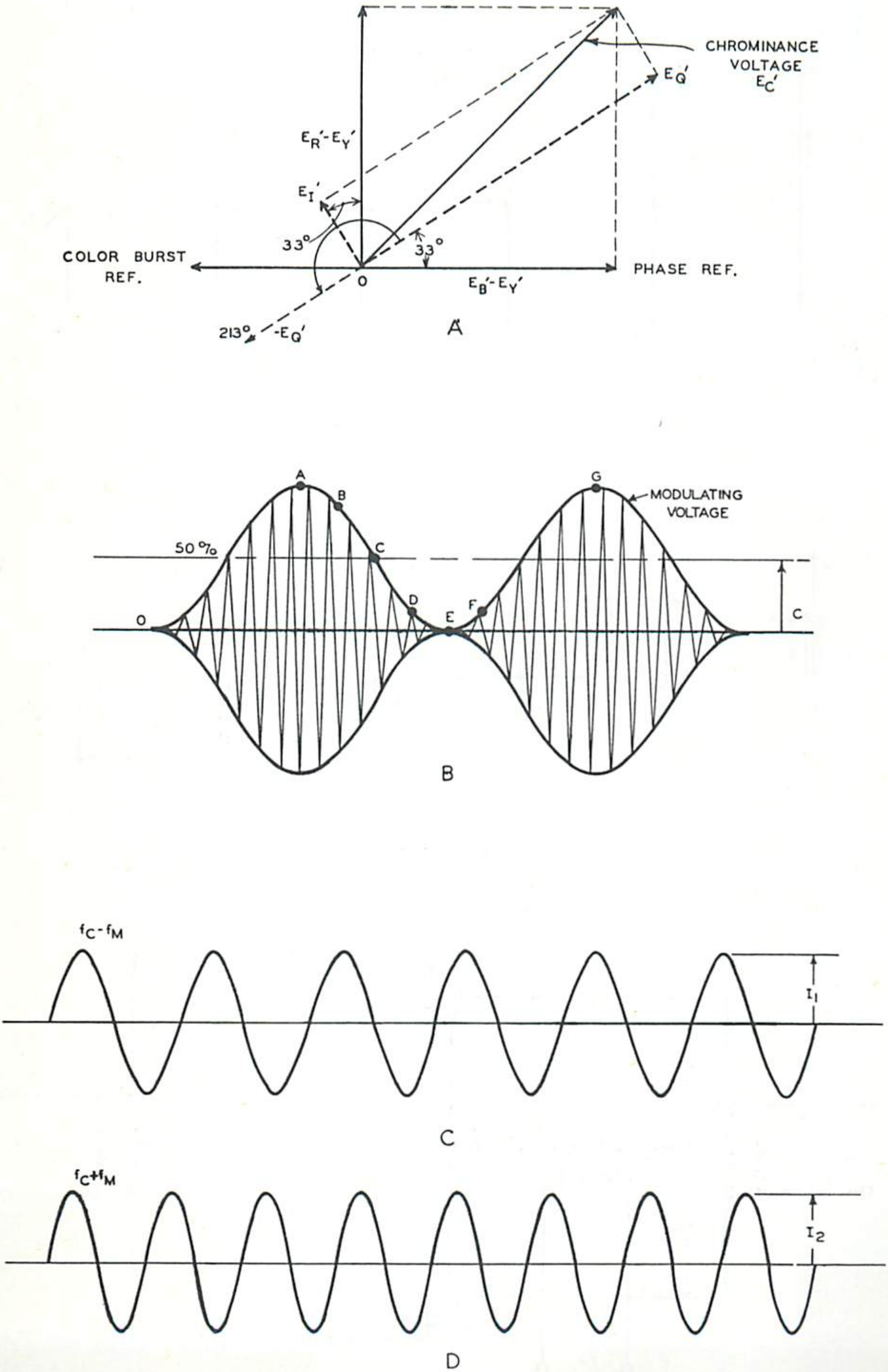

CHROMINANCE VOLTAGE E_C'
E_Q'
E_R'-E_Y'
E_I'
33°
33°
COLOR BURST REF.
O
E_B'-E_Y'
PHASE REF.
213°
-E_Q'
A
A
B
G
MODULATING VOLTAGE
50%
C
O
D
E
F
C
B
f_C-f_M
I_1
C
f_C+f_M
I_2
D

FIGURE 3

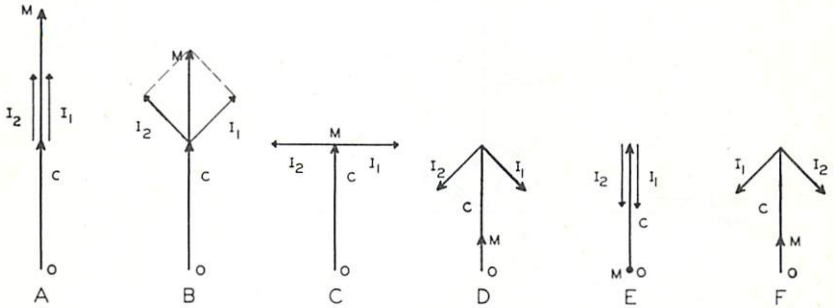


FIGURE 4

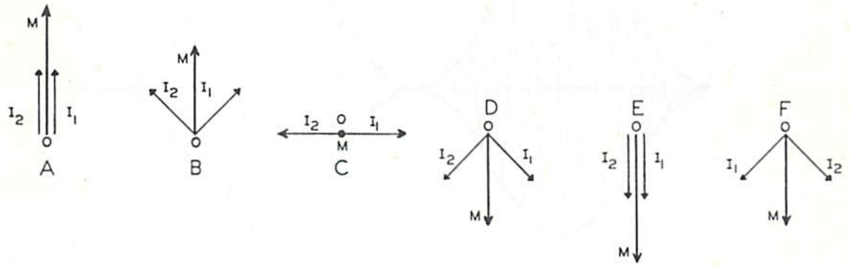


FIGURE 5

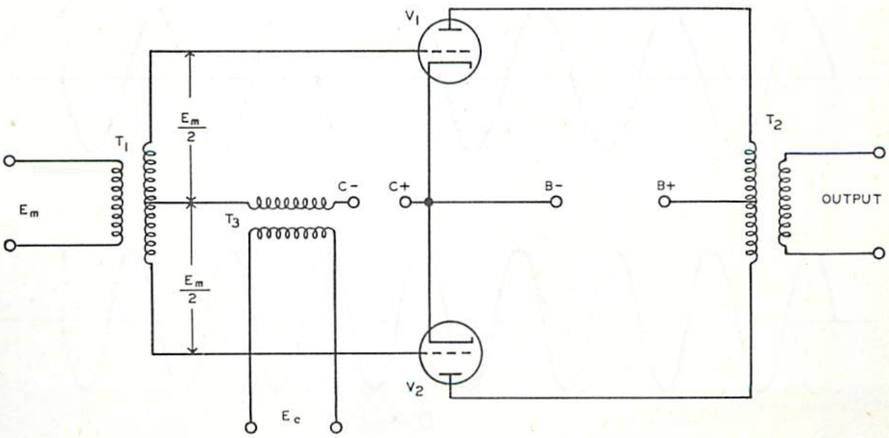


FIGURE 6

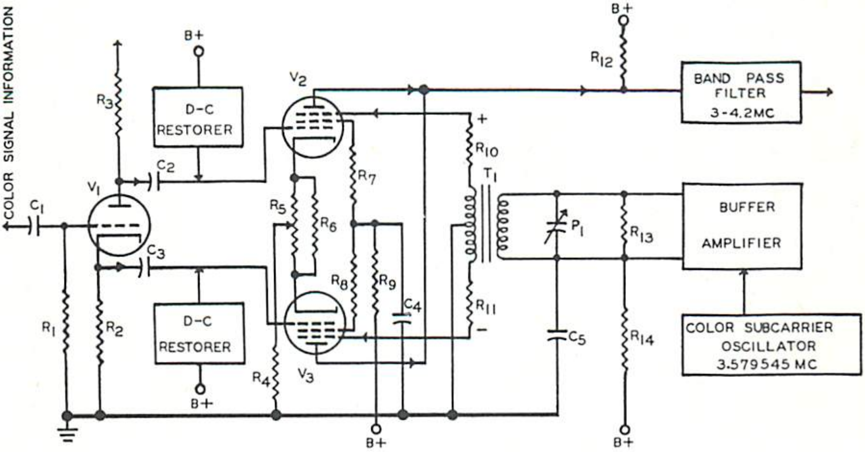


FIGURE 7

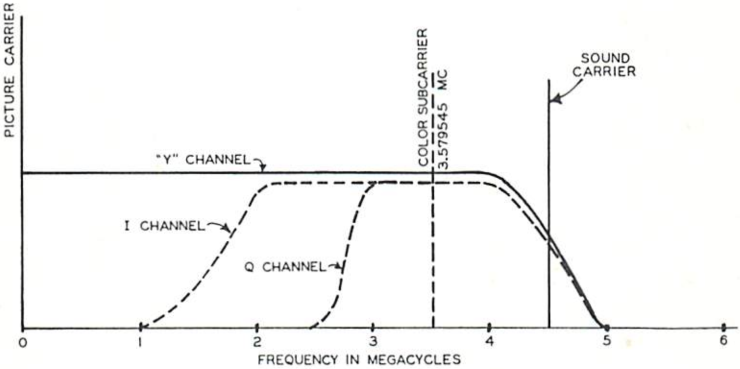


FIGURE 8

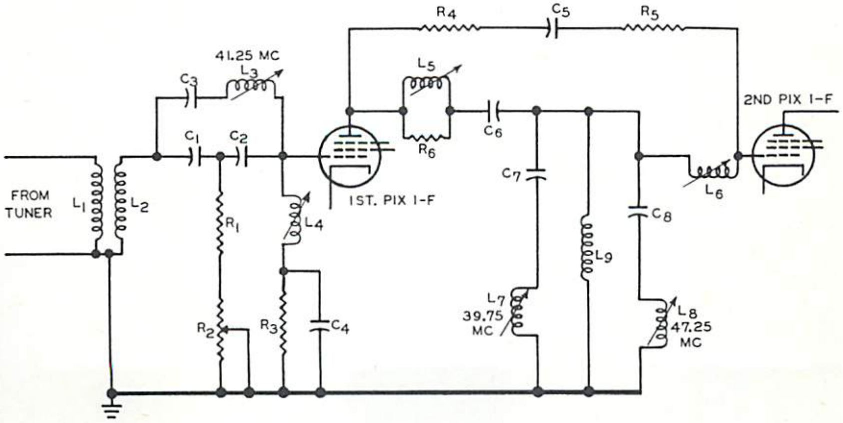


FIGURE 9

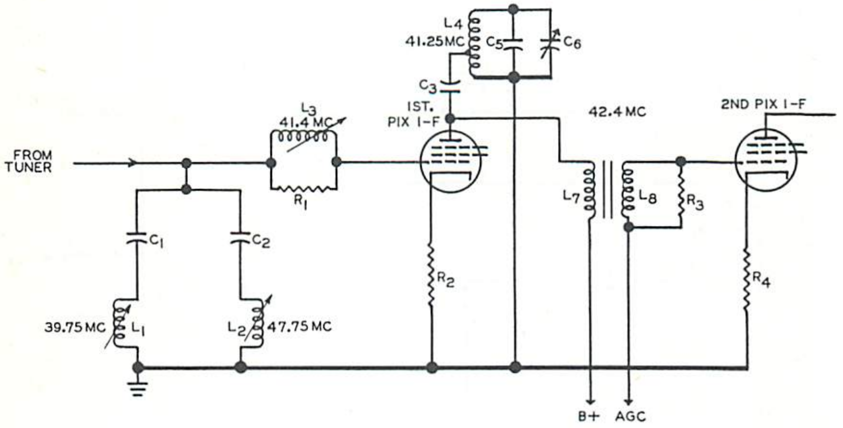


FIGURE 10

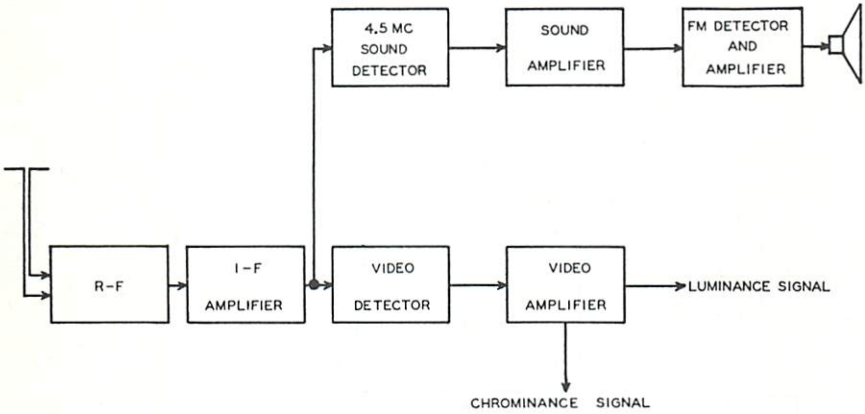


FIGURE 11

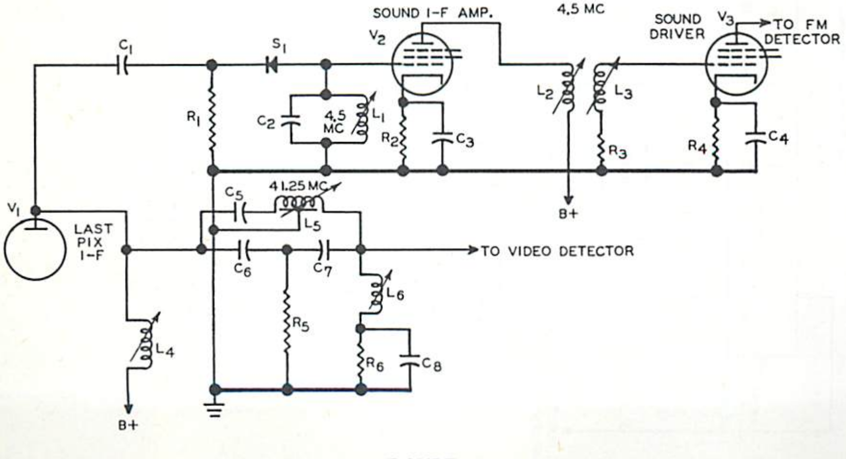
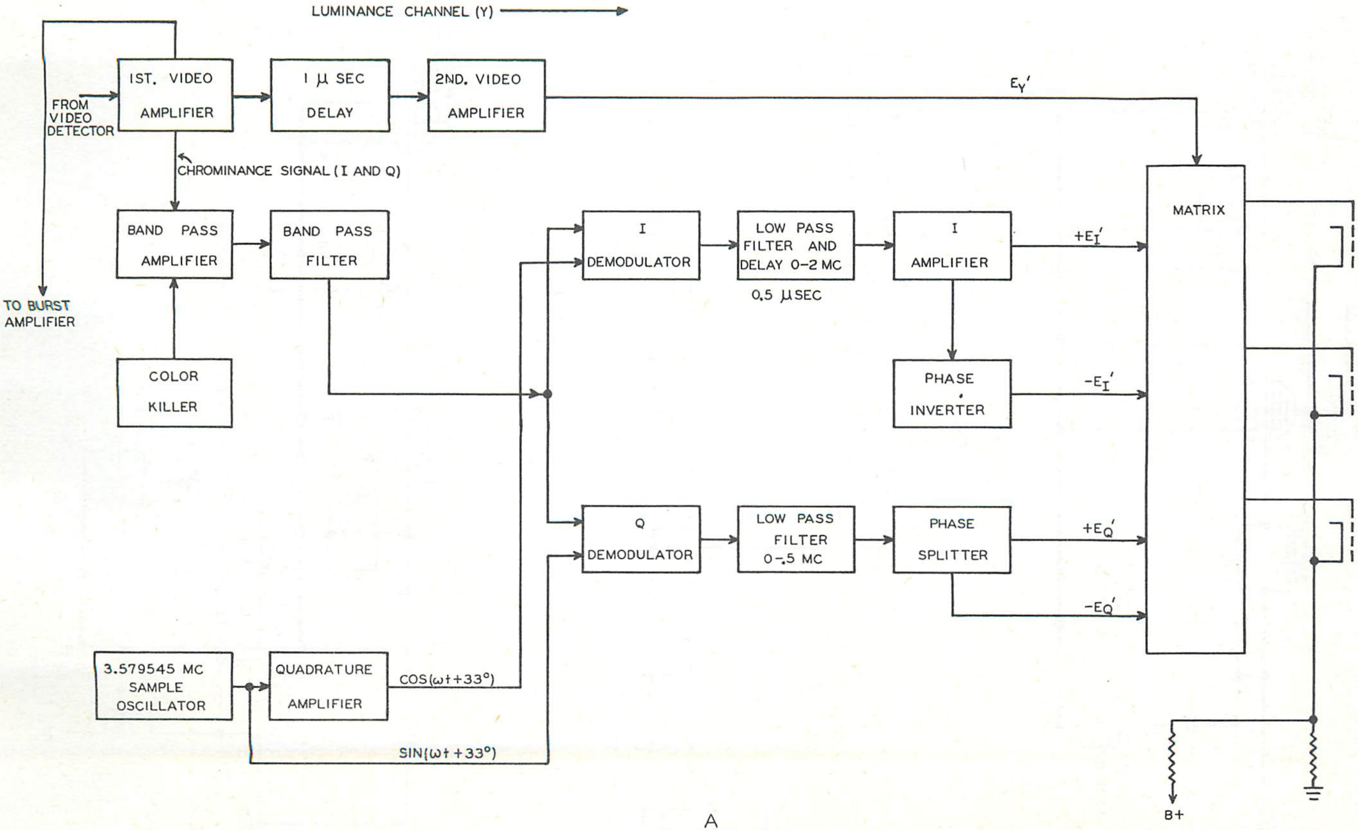
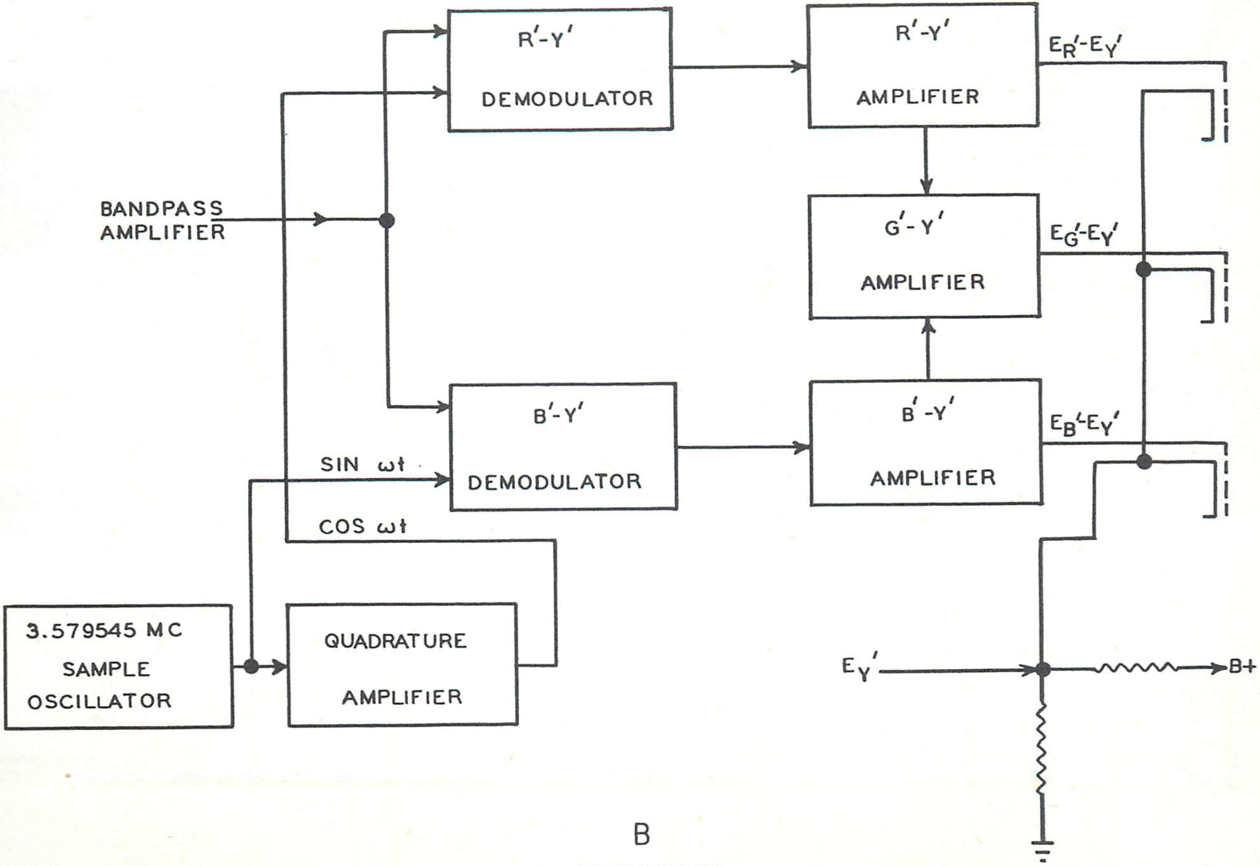


FIGURE 12


LUMINANCE CHANNEL (Y)
FROM VIDEO DETECTOR
1ST. VIDEO AMPLIFIER
1 µ SEC DELAY
2ND. VIDEO AMPLIFIER
E_Y'
TO BURST AMPLIFIER
CHROMINANCE SIGNAL (I AND Q)
BAND PASS AMPLIFIER
BAND PASS FILTER
COLOR KILLER
I DEMODULATOR
LOW PASS FILTER AND DELAY 0-2 MC
0.5 µSEC
I AMPLIFIER
+E_I'
PHASE INVERTER
-E_I'
MATRIX
Q DEMODULATOR
LOW PASS FILTER 0-.5 MC
PHASE SPLITTER
+E_Q'
-E_Q'
3.579545 MC SAMPLE OSCILLATOR
QUADRATURE AMPLIFIER
COS(ωt+33°)
SIN(ωt+33°)
B+

A

FIGURE 13



B

FIGURE 13

T4E-9

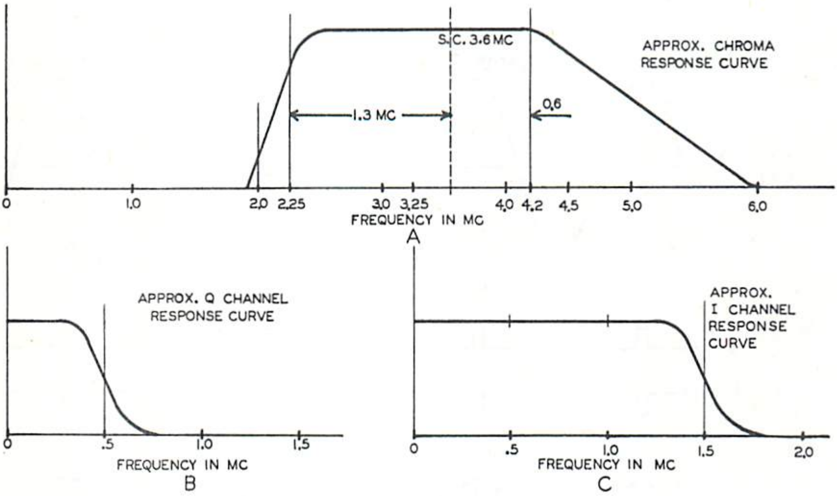


FIGURE 14

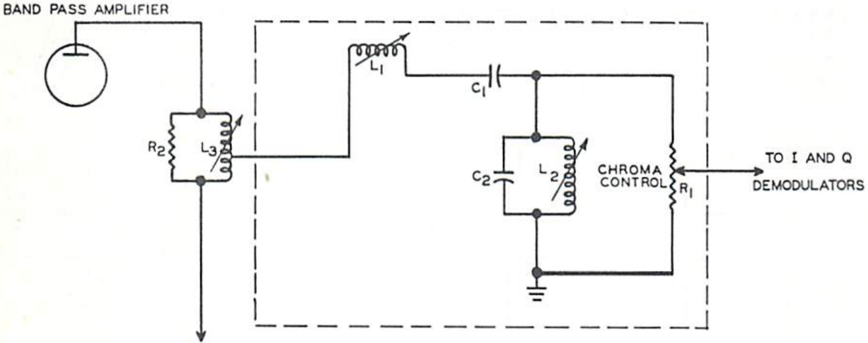


FIGURE 15

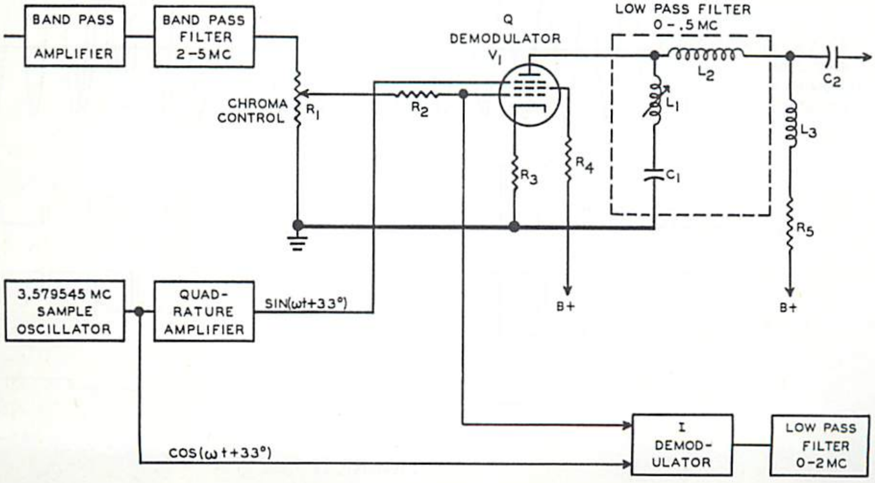


FIGURE 16

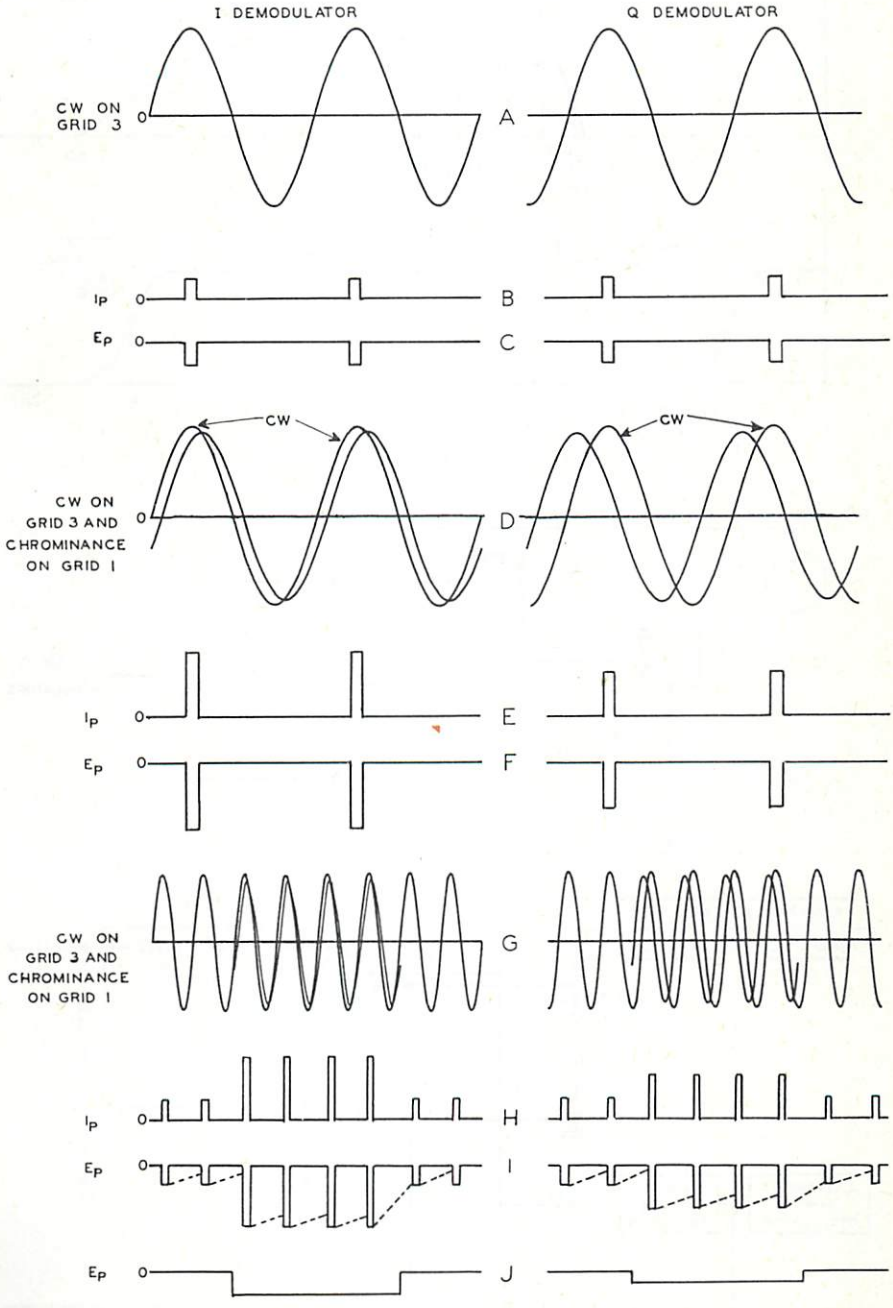
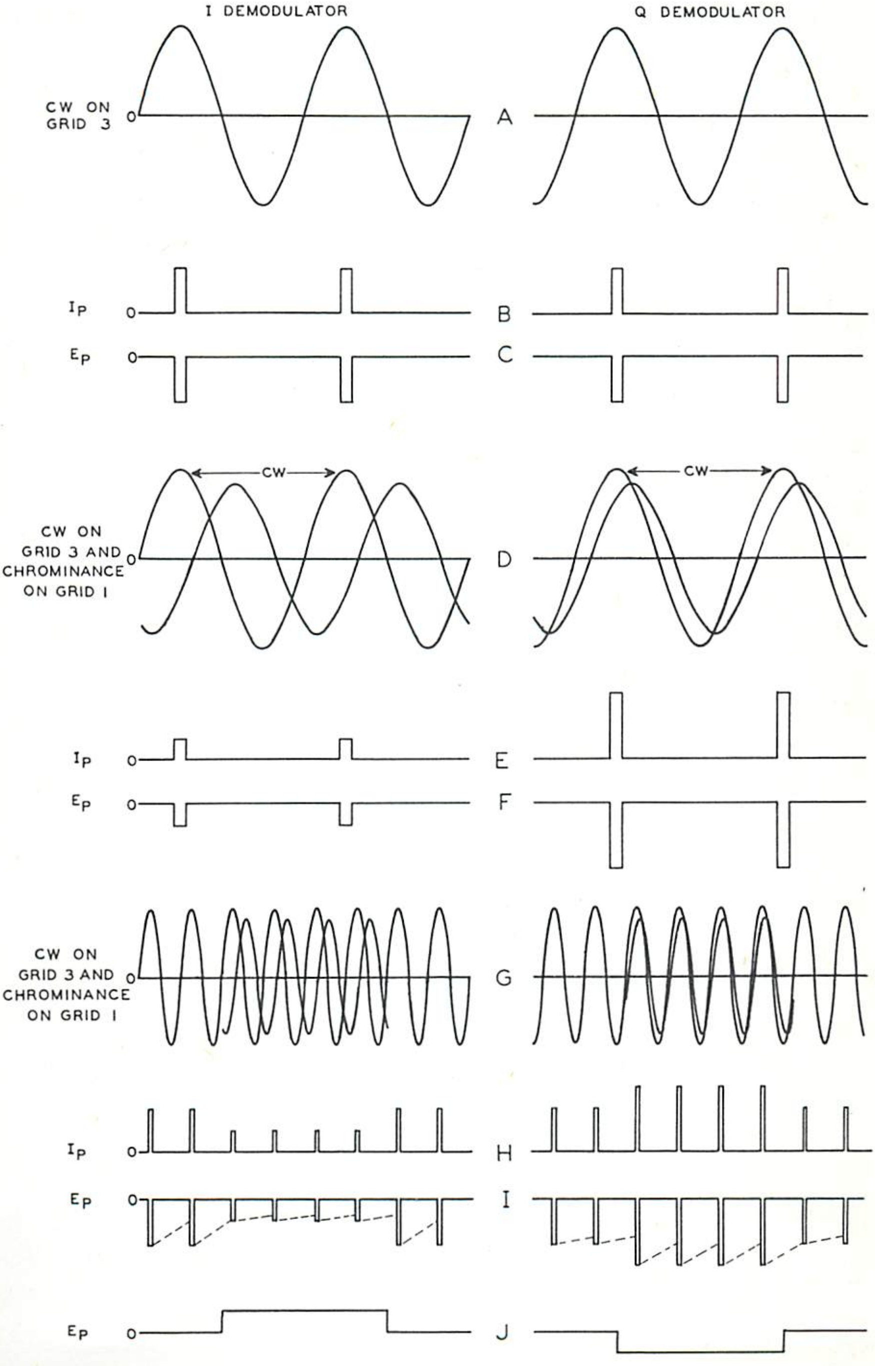

I DEMODULATOR
Q DEMODULATOR
CW ON GRID 3
0
A
IP
0
B
EP
0
C
CW
CW
CW ON GRID 3 AND CHROMINANCE ON GRID I
0
D
IP
0
E
EP
0
F
CW ON GRID 3 AND CHROMINANCE ON GRID I
G
IP
0
H
EP
0
I
EP
0
J

FIGURE 17


I DEMODULATOR
Q DEMODULATOR
CW ON GRID 3
0
A
IP
0
B
EP
0
C
CW
CW
CW ON GRID 3 AND CHROMINANCE ON GRID I
0
D
IP
0
E
EP
0
F
CW ON GRID 3 AND CHROMINANCE ON GRID I
0
G
IP
0
H
EP
0
I
EP
0
J

T4E-9

FIGURE 18

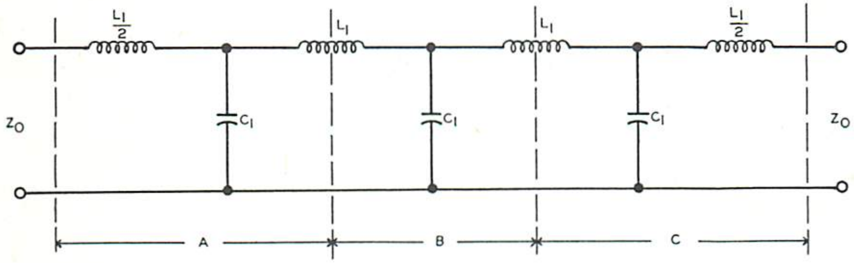
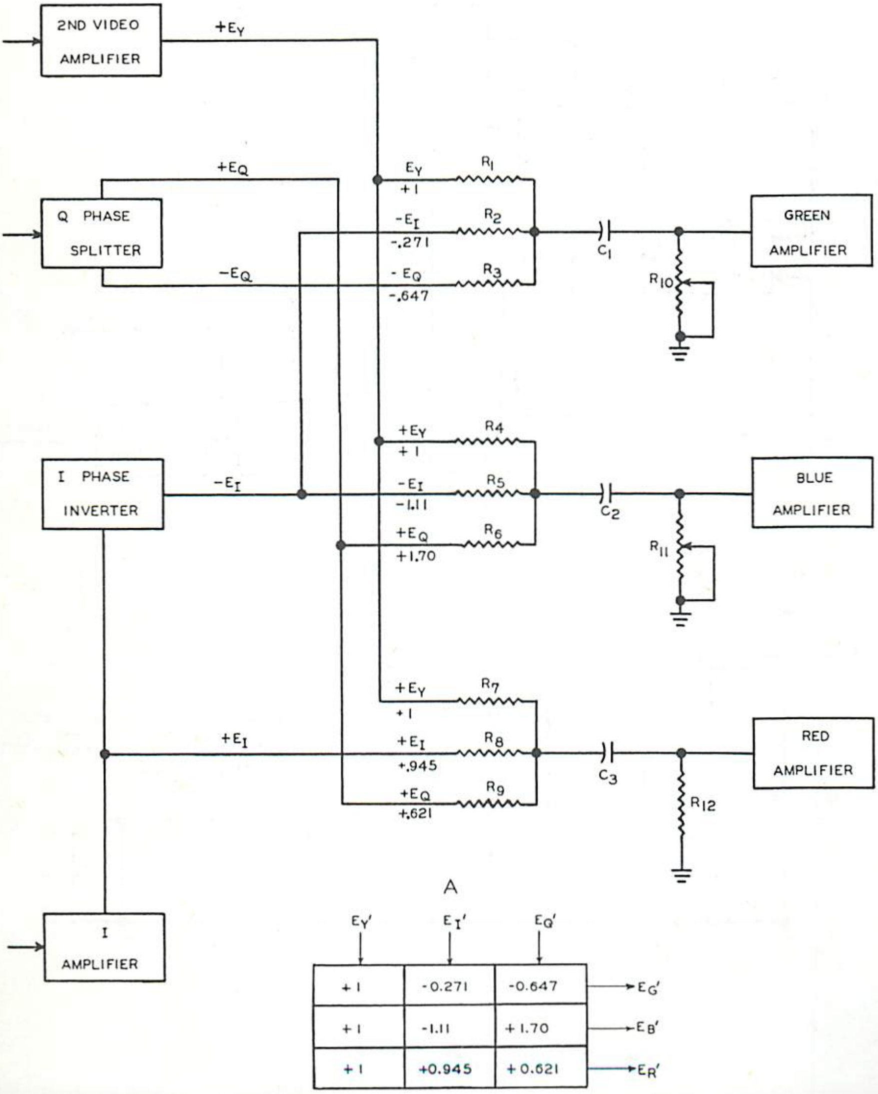


FIGURE 19



E_Y'	E_I'	E_Q'	
+1	-0.271	-0.647	→ E_G'
+1	-1.11	+1.70	→ E_B'
+1	+0.945	+0.621	→ E_R'

FIGURE 20

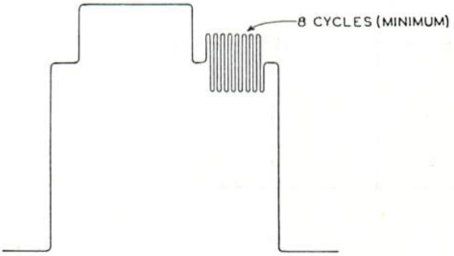


FIGURE 21

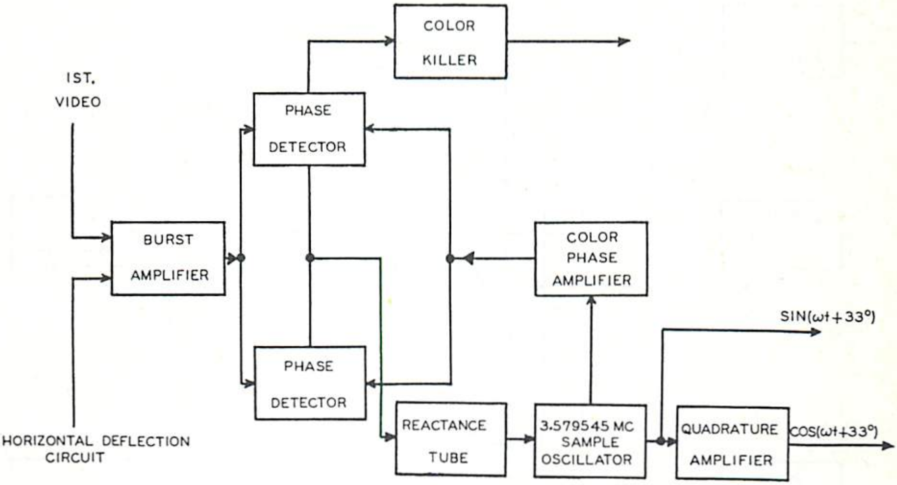


FIGURE 22

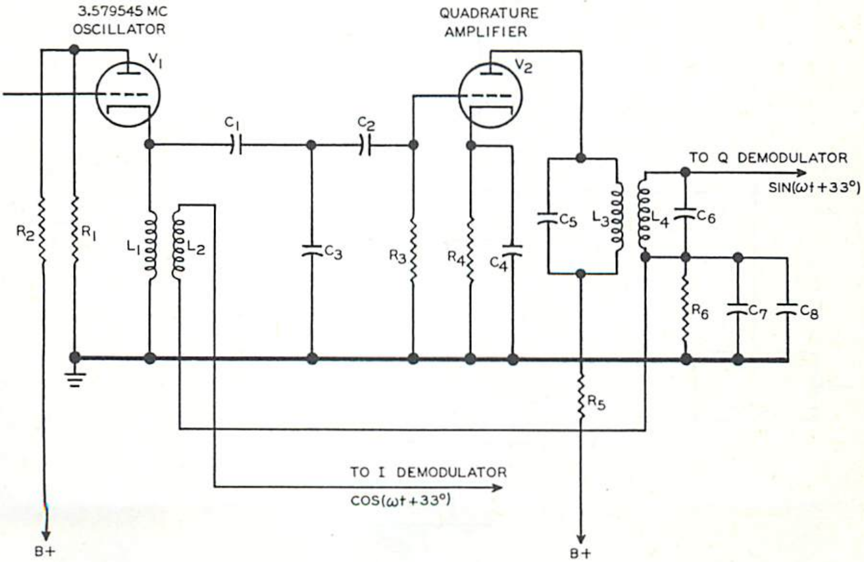


FIGURE 23

FROM OUR *Director's* NOTEBOOK

WHILE IN THE CUSTOMER'S HOME

One of your most important considerations, when performing a service job in the customer's home, should be NEATNESS. Your own personal appearance is important, but so is the way you do your work.

When you pull a TV chassis from the cabinet, there is usually a certain amount of dust and dirt which could soil the rug. Use a drop cloth to prevent this and also to provide a convenient place for your tools and parts. Make sure your tools are clean and your kit orderly.

If you have room, carry a small hand vacuum cleaner to remove dust from the chassis and cabinet. A bottle of glass cleaner and some clean rags for polishing the picture tube face and glass screen will also be helpful.

When you have finished the job, be sure to clean up thoroughly before you leave. Remember, the TV set to the customer is an expensive unit and you should treat it—and the customer's home—accordingly.

Your thoughtfulness and thoroughness will be greatly appreciated by your customer — helping to make your services more and more in demand as your reputation spreads. Yes—neatness is just good . . . smart business.

Yours for success,

W. C. DeVry

DIRECTOR

PRINTED IN U.S.A.